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A Modeling Analysis Program for the
JPL Table Mountain Io Sodium Cloud Data

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16. Abstract

A data quality review for the entire set of the 1981 Region B/C images has been completed and is presented. The review indicates that almost all images are of sufficent quality to be valuable in our analysis of this data set. Five data-correlation studies for the same data set have also been completed and are useful in classifying and studying the sodium cloud morphology and its interactions with solar radiation pressure and the plasma torus. Additional progress in developing new image processing techniques and in improving the Io sodium cloud model is also discussed.

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I. Summary of Research Performed in the First Quarter

Research activities in the first quarter have successfully included (1) completion of a data quality review for the entire set of the 1981 Region B/C images, (2) completion of five data-correlation studies for the entire set of 1981 Region B/C images useful in studying the sodium cloud morphology and its interactions with solar radiation pressure and the plasma torus, and (3) continuation of data processing and model preparation to support image analysis to be undertaken in the second quarter.

1. Data Quality Review of the 1981 Region B/C Images

Observational parameters for the 263 Region B/C images of the 1981 JPL data acquired over 14 nights are summarized in numerical form in Table 1 and in graphical form in Figure 1. Most of these images have been processed only preliminarily to remove background signals. Images on May 4, 5, 12, 13 and June 4 had undergone further processing to remove the instrumental response function and to normalize the image intensity. Because of this, the 110 images (42% of the data set) acquired on May 4, 5, 12 and 13 were chosen and thoroughly reviewed during the first project year. As a result of this review, further refinements in the image processing of these data frames were identified and the development of an improved image processing procedure is now nearing completion. The quality of the remaining 153 images is reviewed here as a prerequisite for selection of images in our model-data studies.

The results of this data quality review are summarized in Table 2 and were compiled by manual inspection of photographical products for each image produced prior to this project by the Image Processing Laboratory of JPL. Most images are composed by adding three data frames, where each data frame generally represents an exposure time of approximately ten minutes. Some images are, however, composed of only one or two data frames. The quality of the images is rated in the right hand column of Table 2 and qualifying comments are also indicated. As can be seen, almost all of the images are of sufficient quality to be valuable in our analysis of this data set. Those images selected for more detailed studies will, as noted earlier, undergo further image processing.

2. Data Correlation Studies

Five data correlation studies are defined in Table 3 for the set of 1981 Region B/C images. Each study provides a different classification for these images based upon their Io geocentric phase angle, ϕ, and their Io System III magnetic longitude angle, ψ. The five classifications are useful in identifying and then studying the effects of radiation pressure, the atom source characteristics, and the plasma torus sink characteristics on the morphology of the sodium cloud. Each correlation study lists those images that are appropriate for the defined classification, regardless of the image data-quality summarized in Table 2. Incorporating the results of Table 2 will then aid in selection and prioritization of images to undergo further image processing and then model-data analysis.

The results of the five data correlation studies of Table 3 are summarized in Tables 4-8, respectively. From Table 4, consecutive image studies are possible on all 14 nights, but short exposure times on March 25 and questionable data quality on June 4 might eliminate these two evenings (see Table 2). From Table 5, cloud stability studies are available for three image sequence pairs (also see Figure 1) which all have good to excellent data quality. If comparisons of these image sequence pairs indicate that the sodium cloud and its interaction with the plasma torus are stable over a few month time interval, then the procedure of comparing images of different dates in the correlation studies III, IV and V will represent a valid multi-faceted look at a common (although periodically time dependent) cloud-torus state. From Table 6, east-west image studies of the cloud morphology may be undertaken and used to explore the nature of east-west difference in the plasma torus also identified by optical torus emissions (Morgan and Fertel, 1984; Morgan, 1985) and by UV emission from the Io plasma torus (Sandel and Broadfoot, 1982; Shemansky and Sandel, 1982). From Table 7, System III variations in the electron properties of the plasma torus may be investigated by comparison and analysis of images. From Table 8, the effects of viewing angle on the cloud morphology may be investigated. The effects of system III variation can also be investigated by comparing images for somewhat similar phase angles, and excellent cases exist for ψ in the range from about 160° to 310° (see Table 8 and Figure 1).

3. Data Processing and Model Preparation

Development of image processing techniques to refine the 1981 Region B/C images has proceeded slower than expected at MIPL (Multimission Image Processing Laboratory of JPL) during the first quarter. Completion and verification of these techniques (Task 1b of Table 9) are now expected in the second quarter. Selected images will then be processed (Task 3a of Table 9) and data-model comparisons will then focus on some of the image studies discussed in the previous section. The new lifetime for sodium atoms in the Io plasma torus further improved in the third quarter of the first project year has been fully integrated in the cloud model this quarter in anticipation of these modeling studies in the second quarter.

II. Program for the Second Quarter

Data processing priority 1.b of Table 9 will be completed and selected images will be processed using this new technique (initiating Task 3.a of Table 9). Modeling analysis of these newly processed images will then begin and specific studies outlined in Table 3 will be pursued.

References

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Morgan, J.S., and Fertel, J.H. (1984) An Imaging Search for Optical East-West Asymmetries in the Io Torus, BAAS, 16, 662.

Sandel, B.R. and Broadfoot, A.L. (1982) Io's Hot Plasma Torus - A Synoptic View from Voyager. J.G.R., 87, 212.

Shemansky, D.E., and Sandel, B.R. (1982) The Injection of Energy into the Io Plasma Torus. J.G.R., 87, 219.

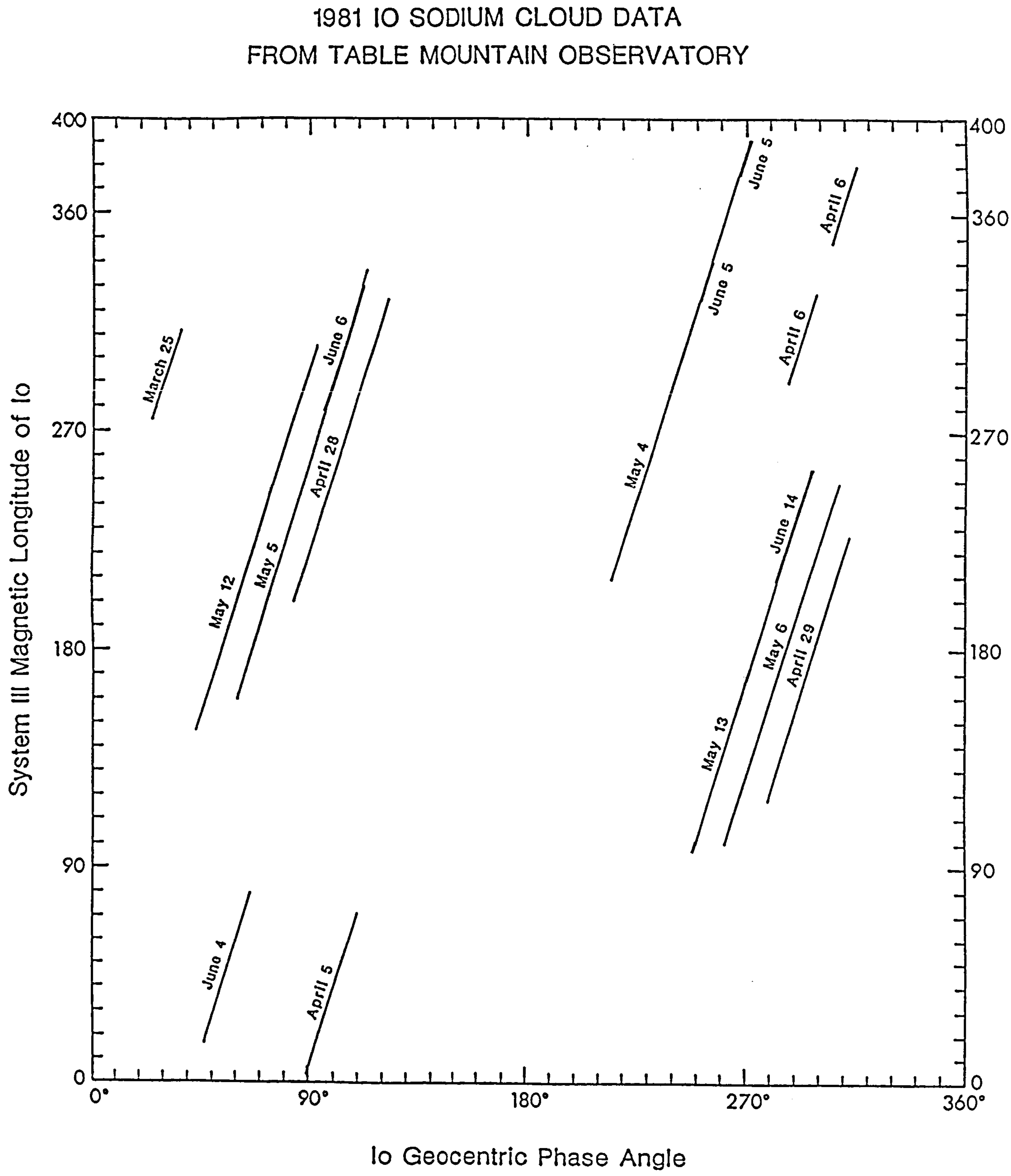

Figure 1. Observing Parameters for 1981 Io Sodium Cloud Images.
The angular coverage for the Io geocentric phase angle and the System III magnetic longitude of Io over which Region B/C images were recorded in the JPL Table Mountain Data Set is indicated for all 14 nights of observations.

Table 1

1981 Region B/C Images: Observing Chronology

Date of Observations	Start Conditions: Time (UT)	Start Conditions: Io Phase Angle (deg)	Start Conditions: Magnetic Longitude of Io† (deg)	End Conditions: Time (UT)	End Conditions: Io Phase Angle (deg)	End Conditions: Magnetic Longitude of Io† (deg)
25 March	7:03	25.2	275.3	8:23	36.5	312.7
5 April	5:18	89.6	365.0	7:40	109.5	70.9
6 April	4:33	287.3	290.7	5:52	298.5	327.3
6 April	6:38	305.1	348.5	7:44	314.4	19.1
28 April	4:21	84.0	200.2	8:50	121.9	324.9
29 April	3:18	279.2	117.5	7:15	312.9	227.1
4 May	3:10	215.4	209.2	9:43	271.4	30.8
5 May	3:17	60.0	159.4	9:25	111.7	330.2
6 May	3:07	262.5	101.4	8:27	307.9	249.5
12 May	3:15	44.5	147.5	8:56	92.4	305.7
13 May	3:20	248.9	96.6	8:51	296.0	249.6
4 June	3:34	47.2	377.3	5:48	66.0	79.5
5 June	3:38	251.7	325.6	4:07	255.8	339.1
5 June	5:27	267.2	16.0	5:55	271.1	29.0
6 June	3:48	95.8	278.0	5:56	113.9	337.3
14 June	3:38	282.7	208.4	5:20	297.1	255.7

†System III (1965)

Table 2

1981 Region B/C Images: Data Quality Review

Date (UT)	UT Start	UT End	Frames	Quality
March 25	-	-	-	- [1]
	5:11	8:15	29	usable[1]
	-	-	-	- [1]

[1] only raw data available; 16 images with most exposures 1 1/2 minutes, since images were so close to Jupiter; must add images for useful results; images were heavily masked in both east and west directions.

Date (UT)	UT Start	UT End	Frames	Quality
April 5	5:18	5:22	18	marginal[2]
	5:25	5:32	19	good[2]
	5:36	5:46	20	good[2]
	5:48	6:03	21	good[2]
	6:05	6:20	22	good (some saturation)[2]
	6:24	6:44	23	good (some saturation)[2]
	6:47	7:02	24	good[2]
	7:04	7:14	25	very good[2]
	7:17	7:24	26	very good[2]
	7:26	7:36	27	very good[2]
	7:40	7:50	28	very good[2]

[2] Part of forward cloud truncated by mask.

Date (UT)	UT Start	UT End	Frames	Quality
April 6 (one)	4:33	4:40	11	good[3]
	4:42	4:52	12	good[3]
	4:54	5:09	13	good[3]
	5:11	5:28	14	good[3]
	5:30	5:50	15	good[3]
	5:52	6:09	16	good[3]
(two)	6:38	6:55	22	good[3,4]
	6:59	7:09	23	good[3,4]
	7:11	7:23	24	good[3,4]
	7:25	7:42	25	good[3,4]
	7:44	8:01	26	good[3,4]

[3] only raw data available.
[4] probably part of forward cloud truncated.

Table 2

(continued)

Date (UT)	UT Start	UT End	Frames	Quality
April 28	4:21	5:01	25-27	good
	4:37	5:13	26-28	very good
	4:49	5:24	27-29	very good
	5:03	5:34	28-30	very good
	5:15	5:45	29-31	very good
	5:25	5:56	30-32	very good
	5:36	6:07	31-33	very good
	5:47	6:18	32-34	very good
	5:58	6:30	33-35	very good
	6:09	6:40	34-36	excellent
	6:31	6:52	36,38[5]	very good
	6:43	7:03	38,39[6]	very good
	6:54	7:16	39,41[7]	very good
	7:07	7:27	41,42[6]	excellent
	7:07	7:37	41-43	excellent
	7:18	7:46.5	42-44	very good
	7:28	7:57.5	43-45	very good
	7:39	8:07	44-46	very good
	7:49	8:18	45-47	very good
	7:59	8:28	46-48	good
	8:10	8:38	47-49	good
	8:20	8:48	48-50	good
	8:30	8:58	49-51	good

[5]two frames only with 9 minute gap in the middle.
[6]two frames only.
[7]two frames with 1 minute gap in center.

Date (UT)	UT Start	UT End	Frames	Quality
April 29	3:18	3:43	1-3	usable
	3:26	3:57	2-4	good
	3:35	4:07	3-5	good
	3:48	4:19	4-6	good
	3:58	4:32	5-7	very good
	4:10	4:42	6-8	very good
	4:22	4:53	7-9	very good
	4:32	5:05	8-10	very good
	4:44	5:16	9-11	very good[8]
	4:55	5:32	10-12	very good
	5:06	5:43	11-13	very good
	5:21	5:55	12-14	very good[9]
	5:33	6:08	13-15	very good

Table 2

(continued)

Date (UT)	UT Start	UT End	Frames	Quality
April 29 (cont.)	5:45	6:21	14-16	good
	5:57	6:32	15-17	good
	6:10	6:42	16-18	good
	6:23	6:52	17-19	good
	6:33	7:02	18-20	good
	6:43	7:14	19-21	good
	6:53	7:25	20-22	good

[8]background level increasing.
[9]little portion of forward cloud truncated by mask.

May 6	3:07	3:25	5-7	usable (twilight)
	3:12	3:36	6-8	good
	3:18	3:46	7-9	good
	3:27	3:57	8-10	very good
	3:37	4:08	9-11	excellent
	3:47	4:20	10-12	excellent
	3:58	4:32(?)	11-13	excellent
	4:09	4:44	12,13[10]	good
	4:22	5:01	13,15[10]	good
	4:50	5:12	15,16[10]	good
	4:50	5:24	15-17	excellent
	5:03	5:35	16-18	excellent
	5:14	5:47	17-19	excellent
	5:25	5:59	18-20	excellent
	5:36	6:10	19-21	excellent
	5:48	6:20	20-22	excellent
	6:00	6:31	21-23	excellent
	6:11	6:43	22-24	excellent
	6:22	6:54	23-25	excellent
	6:33	7:04	24-26	excellent
	6:44	7:14	25-27	very good
	6:55	7:28	26-28	very good
	7:05	7:40	27-29	very good
	7:18	7:52	28-30	very good
	7:30	8:05	29-31	good
	7:41	8:16	30-32	good
	7:54	8:26	31-33	usable[11]
	-	-	32-34	no good

[10]no signal in frame 14.
[11]Jupiter close to horizon.

Table 2

(continued)

Date (UT)	UT Start	UT End	Frames	Quality
June 4	-	-	-	-[12]
	4:57	5:35	12-14	usable[13]
	5:09	5:47	13-15	usable[13]
	5:24	6:00	14-16	usable[13]

[12]perhaps more images, but must examine date on tapes.
[13]forward cloud may be partially truncated.

Date (UT)	UT Start	UT End	Frames	Quality
June 5 (one)	3:38	4:05	5-7	marginal[14]
	3:47	4:18	6-8	good[15]
(two)	5:27	6:09	11-13	good[15]
	5:40	6:25	12-14	good
	5:56	6:39	13-15	good
	6:12	6:54	14-16	good
	6:26	7:07	15-17	good

[14]lots of background noise.
[15]some background noise.

Date (UT)	UT Start	UT End	Frames	Quality
June 6	-	-	-	-[16]
	4:08	4:41	9-11	very good
	4:19	4:53	10-12	very good
	4:30	5:05	11-13	very good
	4:42	5:23	12-14	very good
	4:54	5:42	13-15	very good
	5:08	5:55	14-16	very good
	5:24	6:07	15-17	very good

[16]possibly more images.

Date (UT)	UT Start	UT End	Frames	Quality
June 14	3:38	4:04	5-7	usable[17,18]
	3:47	4:15	6-8	good[18]
	3:56	4:28	7-9	good
	4:05	4:40	8-10	good
	4:17	4:52	9-11	good
	4:29	5:05	10-12	good
	4:41	5:19	11-13	good
	4:53	5:32	12-14	good

[17]signal to noise not very good
[18]portion of forward cloud truncated by mask

Table 3

1981 Region B/C Images: Five Correlation Studies†

I. Consecutive Image Study: $\phi(t)$, $\Psi(t)$

II. Cloud Stability Study: $(\phi_1, \Psi_1) \approx (\phi_2, \Psi_2)$
image sequences separated by 32 days

III. East/West Image Study: $\phi_W = \phi_E + 180°$

$\Psi_E \approx \Psi_W$	only one image-sequence pair
$\Psi_W \approx \Psi_E + 180°$	no image pairs
$\Psi_E \neq \Psi_W$	many comparison images

IV. System III Variability Study: $\phi_1 = \phi_2$, $\Psi_1 \neq \Psi_2$

V. Io Phase Angle Variability Study: $\phi_1 \neq \phi_2$, $\Psi_1 = \Psi_2$

†ϕ = Io Geocentric Phase Angle
Ψ = Io System III Magnetic Longitude Angle

Table 4

1981 Region B/C Images: Correlation Study I

Consecutive Image Study: $\phi(t)$, $\psi(t)$

Image data suitable on all 14 nights

1.	March 25	
2.	April 5	
3.	April 6	
4.	April 28	
5.	April 29	
6.	May 4	(June 5)
7.	May 5	(June 6)
8.	May 6	
9.	May 12	
10.	May 13	(June 14)
11.	June 4	

Table 5

1981 Region B/C Images: Correlation Study II

<u>Cloud Stability Study</u>: $(\phi_1, \psi_1) \approx (\phi_2, \psi_2)$

Three Image Sequence Pairs Suitable

(May 5, June 6)	Io east of Jupiter
(May 4, June 5)	Io west of Jupiter
(May 13, June 14)	Io west of Jupiter

Table 6

1981 Region B/C Images: Correlation Study III

East/West Image Study: $\phi_W = \phi_E + 180°$

1. East Images

ϕ_E	ϕ_W
March 25	May 4
May 12	May 4, May 6, May 13, June 5 (one, two)
June 4	May 4
May 5	April 29, May 4, May 6, May 13, June 5 (one, two)
June 6	April 6 (one), April 29, May 4, May 13, June 14
April 28	April 6 (one)*, April 29, May 4, May 6, May 13, June 5 (two), June 14

2. West Images

ϕ_E	ϕ_W
May 4	March 25, April 5, April 28, May 5, May 12, June 4
June 5 (one)	May 5, May 12
June 5 (two)	April 5, April 28, May 5, May 12
May 13	April 5, April 28, May 5, May 12, June 6
May 6	April 5, April 28, May 5, May 12, June 6
April 6 (one)	April 5, April 28*, May 5, June 6
April 6 (two)	no candidates
June 14	April 5, April 28, May 5, June 6
April 29	April 5, April 28, May 5, June 6

*$\psi_E \approx \psi_W$ in addition

Table 7

1981 Region B/C Images: Correlation Study IV

System III Variability Study†: $\phi_1 = \phi_2, \Psi_1 \neq \Psi_2$

Io East of Jupiter

ϕ	Date	Ψ
50	June 4	26
	May 12	167
60	June 4	58
	May 12	198
65	June 4	72
	May 5	172
	May 12	212
70	May 5	190
	May 12	231
80	May 5	222
	May 12	263
90	April 5	5
	April 28	219
	May 5	256
	May 12	294
100	April 5	37
	April 28	251
	May 5	288
	June 6	288
110	April 5	70
	April 28	283
	May 5	322
	June 6	322

Io West of Jupiter

ϕ	Date	Ψ
250	May 13	102
	May 4	323
255	May 13	118
	May 4	338
	June 5	338
260	May 13	133
	May 4	353
270	June 5	25
	May 4	25
	May 6	128
	May 13	167
280	May 6	157
	May 13	197
290	April 29	153
	May 6	190
	May 13	232
	June 14	232
	April 6(one)	299
300	April 29	185
	May 6	223
305	April 29	202
	May 6	238
	April 6(two)	350
310	April 6	4
	April 29	219

†angles ϕ and ψ given in degrees

Table 8

1981 Region B/C Images: Correlation Study V

Io Phase Angle Variability Study†: $\phi_1 \neq \phi_2$, $\psi_1 = \psi_2$

ψ	Date	ϕ
0	May 4	262
	April 16(two)	309
10	May 4	265
	April 6(two)	312
20	June 4	48
	April 5	94‡
	May 4	268‡
	June 5(two)	268‡
30	June 4	51
	April 5	97‡
	May 4	271‡
40	June 4	54
	April 5	100
50	June 4	57
	April 5	103
60	June 4	60
	April 5	106
70	June 4	63
	April 5	109
110	May 13	253
	May 6	266
120	May 13	256
	May 6	268
	April 29	280
130	May 13	259
	May 6	271
	April 29	283

ψ	Date	ϕ
140	May 13	262
	May 6	274
	April 29	286
150	May 12	45
	May 13	265
	May 6	277
	April 29	289
160	May 12	48
	May 5	60
	May 13	268
	May 6	280
	April 29	292
170	May 12	51
	May 5	63
	May 13	271
	May 6	283
	April 29	295
180	May 12	54
	May 5	66
	May 13	274
	May 6	286
	April 29	298
190	May 12	57
	May 5	69
	May 13	277
	May 6	289
	April 29	301

Table 8

(continued)

Ψ	Date	φ
200	May 12	60
	May 5	72
	May 13	280
	May 6	293
	April 29	304
210	May 12	63
	May 5	75
	April 28	87
	May 4	216
	May 13	283
	June 14	283
	May 6	296
	April 29	307
220	May 12	66
	May 5	78
	April 28	90
	May 4	219
	May 13	286
	June 14	286
	May 6	299
	April 29	310
230	May 12	69
	May 5	81
	April 28	93
	May 4	222
	May 13	289
	June 14	289
	May 6	302
240	May 12	72
	May 5	84
	April 28	96
	May 4	225
	May 13	292
	June 14	292
	May 6	305

Ψ	Date	φ
250	May 12	75
	May 5	87
	April 28	99
	May 4	228
	June 14	295
260	May 12	78
	May 5	90
	April 28	102
	May 4	231
270	May 12	81
	May 5	94
	April 28	105
	May 4	234
280	March 25	26
	May 12	84
	June 6	96
	May 5	97
	April 28	108
	May 4	237
290	March 25	29
	May 12	87
	June 6	99
	May 5	100
	April 28	111
	May 4	240
300	March 25	32
	May 12	90
	June 6	102
	May 5	103
	April 28	114†
	May 4	243
	April 6(one)	290†

Table 8

(continued)

Ψ	Date	ϕ
310	March 25	36
	June 6	105
	May 5	106
	April 28	117‡
	May 4	246
	April 6(one)	294‡
320	June 6	108
	May 5	109
	April 28	120‡
	May 4	249
	April 6(one)	297‡
330	June 6	111
	May 4	252
	June 5(one)	252
350	May 4	258
	April 6(two)	306

†Angles ϕ and ψ given in degrees

‡Io phase angles differ by approximately 180°

Table 9

Data Processing Priorities

1. Improve Techniques to Remove Distortion in the Brightness Distribution of Images

    a. Implement improved background subtraction techniques for images.

    b. Improve techniques for removal of image distortion near Io produced by continuum light scattered by Io.

2. Determine the Absolute Brightness Calibration for the Images

    a. Analyze 1981 1-D slit data on Io's disk and Region A image data to establish an absolute brightness calibration for the 1981 data.

    b. Analyze 1976-79 1-D slit data on Io's disk to establish a brightness calibration for the 1976-79 data.

3. Prepare Images for Modeling Analysis

    a. Using improved techniques in 1 above, remove brightness morphology distortions in a selected subset of images.

    b. Using the information in 2 above, absolutely calibrate this selected subset of images.